

## 8 ELEVATED MEASUREMENT COMPARISON

As discussed in Section 2.6, an *Elevated Measurement Comparison* is performed by comparing each measurement from the survey unit to the  $DCGL_{EMC}$ . If the survey unit is being compared to a reference area, the net survey unit measurement is first obtained by subtracting the mean of the reference area measurements. A net survey unit measurement that equals or exceeds the  $DCGL_{EMC}$  is an indication that a survey unit may contain residual radioactivity in excess of the release criterion.

In addition to direct measurements or samples at discrete locations, parts of each survey unit will also be scanned. For the quantitative measurements obtained at discrete locations, performing the EMC is a straightforward comparison of two numerical values. Some sophisticated scanning instrumentation is also capable providing quantitative results with a quality approaching those from direct measurements or samples. Other scanning measurements, however, may be more qualitative. In that case, *action levels* should be established for the scanning procedure so that areas with concentrations that may exceed the  $DCGL_{EMC}$  are marked for a quantitative measurement.

### 8.1 Introduction

The Elevated Measurement Comparison (EMC) against measurements taken on a systematic grid are discussed in Section 8.1. The use of the EMC during scans is discussed in Section 8.2. Area factors are discussed in Section 8.3, and an example is given in Section 8.4.

The statistical tests may not fail a survey unit when there are only a very few high measurements. The EMC is used so that unusually large measurements will receive proper attention regardless of the outcome of those tests—and any area that may have the potential for significant dose contributions will be identified. The EMC is intended to flag potential failures in the remediation process, and cannot be used to determine whether or not a site meets the release criterion until further investigation is done.

The derived concentration guideline level for the EMC is:  $DCGL_{EMC} = (F_{grid})(DCGL_W)$ , where  $F_{grid}$  is the area factor for the area of the systematic grid area used (see Section 3.5.4). Note that  $DCGL_{EMC}$  is an *a priori* limit, established both by the  $DCGL_W$  and by the survey design (i.e., grid spacing and scanning MDC). The true extent of an area of elevated activity can only be determined after performing the survey and then taking additional measurements if an elevated measurement is found. Upon the completion of further investigation, the *a posteriori* limit,  $DCGL_{EA} = (F_{actual})(DCGL_W)$ , can be established using the value of the area factor,  $F$ , appropriate for the *actual measured area of elevated concentration*. The area that is considered elevated is that bounded by concentration measurements at or below the  $DCGL_W$ .

If residual radioactivity is found in an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule can be used to ensure that the total dose is within the release criterion:

$$\frac{\delta}{DCGL_w} + \frac{(\text{average concentration in elevated area} - \delta)}{(\text{area factor for elevated area})(DCGL_w)} < 1$$

If there is more than one elevated area, a separate term should be included for each. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available.

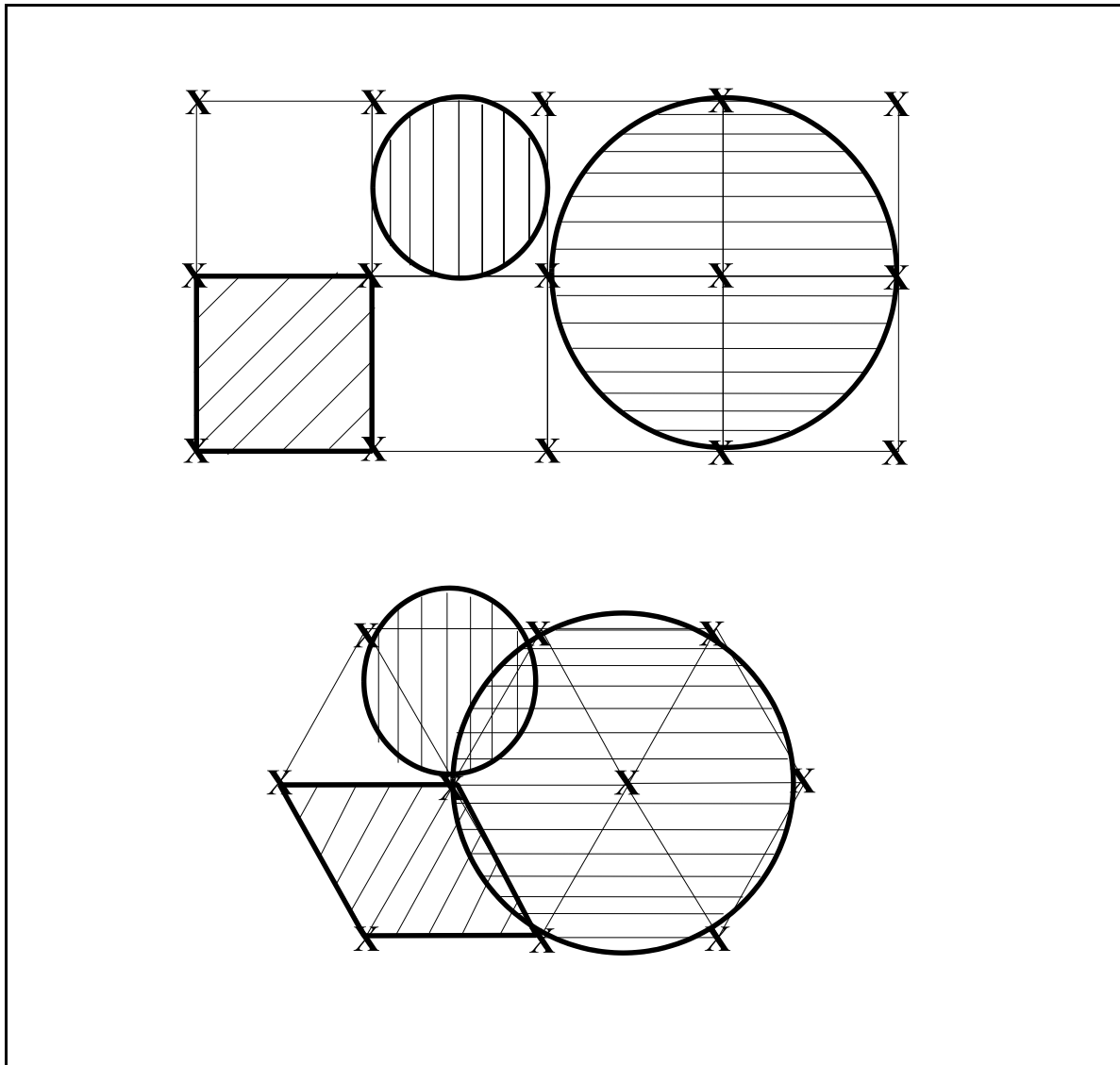
The preceding discussion primarily concerns Class 1 survey units. Measurements exceeding  $DCGL_w$  in Class 2 or Class 3 areas may indicate survey unit mis-classification. Scanning coverage requirements for Class 2 and Class 3 survey units are less stringent than for Class 1 survey units.

If the investigation levels of Section 2.6 are exceeded, an investigation should (1) assure that the area of elevated activity discovered meets the release criterion and (2) provide reasonable assurance that other undiscovered areas of elevated activity do not exist. If further investigation determines that the survey unit was misclassified with regard to contamination potential, a resurvey using the method appropriate for the new survey unit classification may be appropriate.

## 8.2 Comparison Against Individual Measurements

The  $DCGL_{EMC}$  is calculated on the basis of the grid area, since this is about the same as the largest circular area that has some chance of being missed when sampling on the grid. Figure 8.1 shows both a square and a triangular sampling grid. On the square grid, with grid area  $L^2$ , the small circular area with diameter  $L$  has an area of  $\pi(L/2)^2 = 0.785L^2$ . A circle with area  $L^2$  would have a radius of  $0.564L$ . From Figure 3.8, a circle of that radius has only about a 10% chance of being missed. The triangular grid is a little more efficient. The grid area is the rhombus formed from two of the triangles, and has area of  $0.866L^2$ . A circle with that area has a radius of  $0.525L$ , and, from Figure 3.8, has less than a 5% chance of being missed. The significance of this is that when no measurement exceeds the  $DCGL_{EMC}$ , it is unlikely that there are areas remaining that could cause the release criterion to be exceeded. The survey is planned in anticipation of a negative result, and provides a quantitative measure of risk when no elevated measurements are found, as well as an objective, dose-based definition of what is considered elevated.

When a measurement is found to exceed the  $DCGL_{EMC}$ , there is more work to be done before the question of compliance can be answered. An individual elevated measurement on a systematic grid could conceivably represent an area three to four times as large as the systematic grid area used to define the  $DCGL_{EMC}$ . This is the area bounded by the nearest neighbors of the elevated measurement location, as shown by the large circles in Figure 8.1. However, the elevated area may also be smaller than the grid area. Since the allowable concentration generally increases as the elevated area decreases in size, further investigation is necessary to determine both the actual area and average concentration. The boundary of the elevated area is defined by concentration measurements at or below the  $DCGL_w$ . Once the actual elevated area is found, the corresponding area factor,  $F_{\text{actual}}$  is calculated in order to determine the release criterion for the elevated area:  $DCGL_{EA} = (F_{\text{actual}})(DCGL_w)$ .



**Figure 8.1 Square (top) and Triangular (bottom) Sampling Grids and Grid Areas**  
(Circular elevated areas of radius  $L/2$  and  $L$  are shown for comparison)

The problem remaining is to determine whether or not the average concentration in the elevated area meets the  $DCGL_{EA}$ . This is essentially the same problem as the original one of determining whether or not the average concentration in the survey unit meets the  $DCGL_w$ . This is not to suggest that it is necessary to define the elevated area as a separate survey unit and conduct a new survey to determine its compliance with the  $DCGL_{EA}$ . For cases in which the decision is too close to call, it may be useful to keep this analogy in mind when planning a resolution to the problem. It will also be useful in planning the investigation of the elevated area.

There will be many types and sizes of elevated areas. In many cases, it may be obvious whether or not the elevated area exceeds the release criterion based on the measurements taken during the investigation, without performing an additional survey or performing additional statistical tests. Obviously, if the elevated area mean exceeds the  $DCGL_{EA}$ , the survey unit fails. If the elevated area mean is less than the  $DCGL_{EA}$  by more than the standard error of the mean, ALARA

considerations will usually determine whether or not further remediation is necessary. As with any measurements, the DQO process should be used in planning the investigation of the elevated area, and what decisions will be made based on the results.

Some other considerations that may arise are:

- (1) The variability of concentrations in the elevated area is likely to exceed that of any background variations, so additional reference area measurements will not usually be needed. If the survey unit is being compared to a reference area, the boundary of the elevated area should be determined by measurements at or below the  $DCGL_w$  added to the mean reference area measurement. The elevated area mean minus the mean reference area concentration should not exceed the  $DCGL_{EA}$ .
- (2) There may be elevated areas within the elevated area: There may exist a smaller area within the elevated area that has concentrations high enough to exceed the release criterion when considered separately, even though the average concentration over the entire elevated area is within the  $DCGL_{EA}$ .

### 8.3 Comparison Against Scanning Measurements

The measurement results obtained during scanning are inherently more qualitative in nature than those obtained on the systematic grid. In Class 1 survey units, much of the survey design depends on the ability to detect areas exceeding the  $DCGL_{EMC}$  during scanning. This is the essence of the requirement that the scanning MDC be below the  $DCGL_{EMC}$ . In practice, this means that an operating procedure for flagging suspect locations during scanning be devised to ensure that potential elevated areas be investigated. Then, as is the case with measurements on the systematic grid that exceed the  $DCGL_{EMC}$ , the suspect area must be investigated to determine the area and average concentration of the elevated area. In many cases, it would be prudent to set the criteria for flagging elevated areas conservatively. If this is done, and subsequent quantitative measurements indicate that the  $DCGL_{EMC}$  is not actually being exceeded, nothing further would generally be necessary unless for ALARA considerations. If measurements above the stated scanning MDC are found by sampling or by direct measurement at locations that were not flagged by the scanning survey, this may indicate that the scanning method did not meet the DQOs.

Scanning requirements for Class 2 and Class 3 survey units are less stringent both with regard to the coverage and sensitivity. This is possible because of the screening process necessary to show that these areas are not highly contaminated (Sections 2.2.2 and 2.2.3). For this reason, the investigation levels are lower than in Class 1 areas (Section 2.5.7).

### 8.4 Area Factors

Area factors have been discussed in Sections 2.2.1 and 3.8.2. These area factors should be calculated using dose pathway models and assumptions that are consistent with those used to calculate the  $DCGL_w$ . In this section, examples of area factors for both indoor and outdoor survey units are given.

The example outdoor area factors listed in Table 8.1 were calculated using RESRAD for Windows 5.70 (ANL/EAD/LD-2). For each radionuclide, all dose pathways were calculated assuming an initial concentration of 1 pCi/g. The default area of contamination in RESRAD 5.7 is 10000 m<sup>2</sup>, so for this size area, the area factor for all radionuclides is equal to one. Area factors for other size areas were computed by taking the ratio of the dose per unit concentration calculated by RESRAD for the default 10000 m<sup>2</sup> to that calculated for 1, 3, 10, 30, 100, 300, 1000, and 3000 m<sup>2</sup>. The other RESRAD default values were not changed except to adjust the length parallel to aquifer to be consistent with area of contamination..

The area factors for selected radionuclides are plotted in Figure 8.2. There it can be seen that radionuclides generally fall into three groups. Those that deliver dose primarily through internal pathways, those that deliver dose primarily through the external pathway, and a few for which both are important. Generally, the radionuclides that deliver dose via internal pathways (e.g., <sup>14</sup>C, <sup>90</sup>Sr) have the highest area factors. These area factors scale with the area in a manner suggesting that it is the total inventory of the radionuclides that is most important. The area factors for radionuclides that deliver dose primarily through external gamma have lower area factors, reflecting the fact that these radionuclides can deliver dose at a distance. In a mixture, it will generally be these radionuclides that will have the limiting area factors. Fortunately, these are also the radionuclides most easily detected using scanning techniques.

Notice that Figure 8.2 is plotted on a log-log scale. Linear interpolation on this figure corresponds to logarithmic interpolation in Table 8.1 for areas between those listed. For example, if the area factor for <sup>241</sup>Am is needed for 25 m<sup>2</sup>, the table lists 96.3 for 10 m<sup>2</sup> and 44.2 for 30 m<sup>2</sup>. To interpolate, take the base 10 logarithms of these numbers:

$$\begin{aligned}\log_{10}(10) &= 1 \\ \log_{10}(30) &= 1.477 \\ \log_{10}(25) &= 1.398 \\ \log_{10}(13.4) &= 1.127 \\ \log_{10}(4.99) &= 0.698.\end{aligned}$$

The interpolation is done using these values:

$$\begin{aligned}\log_{10}(A_{25}) &= \log_{10}(13.4) \\ &+ [\log_{10}(25) - \log_{10}(10)] \{ [\log_{10}(4.99) - (\log_{10}(13.4))] / [\log_{10}(30) - \log_{10}(10)] \} \\ &= 1.127 + [1.398 - 1] \{ [0.698 - 1.127] / [1.477 - 1] \} \\ &= 1.127 + [0.398] \{ [-0.429] / [0.477] \} \\ &= 0.769\end{aligned}$$

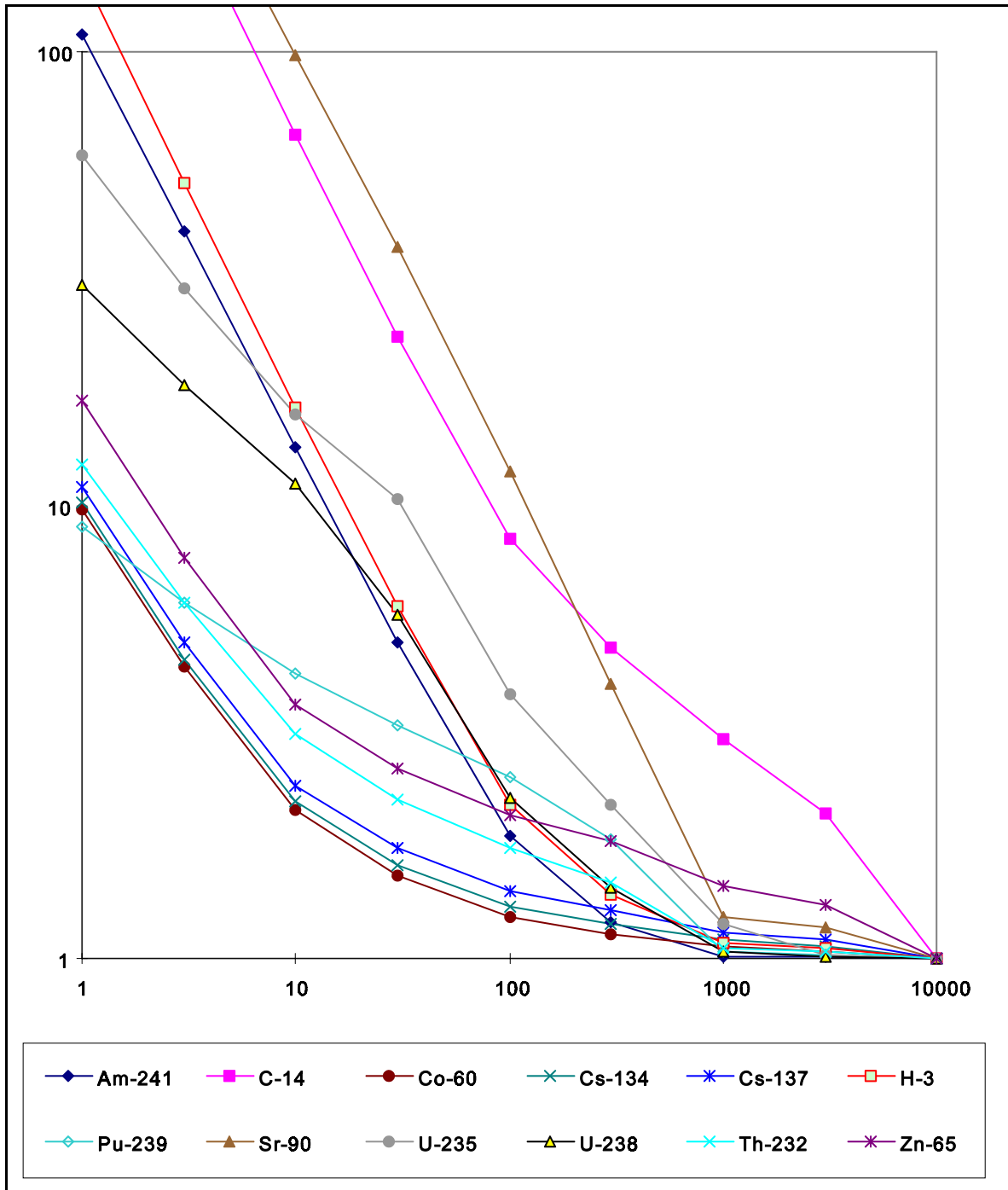
Therefore,  $A_{25} = 10^{(0.769)} = 5.88$ .

Example indoor area factors listed in Table 8.2 were calculated using RESRAD BUILD for Windows 2.11 (ANL/EAD/LD-3, 1994). For each radionuclide, all dose pathways were calculated assuming an initial concentration of 1 pCi/m<sup>2</sup>. The default area of contamination in

RESRAD BUILD is 36 m<sup>2</sup>. The other areas compared to this value were 1, 4, 9, 16, or 25 m<sup>2</sup>. No other changes to the RESRAD BUILD default values were made. Dose was computed for one receptor, who spent 100% of time in the contaminated room. The area factors were then computed by taking the ratio of the dose per unit concentration calculated by RESRAD BUILD for the default 36 m<sup>2</sup> to that calculated for the other areas listed. Thus, if the guideline limit concentration for residual radioactivity distributed over 36 m<sup>2</sup> is multiplied by this value, the resulting concentration distributed over the specified smaller area delivers the same average dose. There are obviously many other exposure scenarios which may result in different area factors.

**Table 8.1 Example Outdoor Area Factors**

<b>Nuclide</b>	<b>10000m<sup>2</sup></b>	<b>3000 m<sup>2</sup></b>	<b>1000 m<sup>2</sup></b>	<b>300 m<sup>2</sup></b>	<b>100 m<sup>2</sup></b>	<b>30 m<sup>2</sup></b>	<b>10 m<sup>2</sup></b>	<b>3 m<sup>2</sup></b>	<b>1 m<sup>2</sup></b>
<b>Am-241</b>	1.00	1.01	1.01	1.20	1.86	4.99	13.4	40.2	109
<b>C-14</b>	1.00	2.09	3.06	4.84	8.40	23.6	65.7	207	609
<b>Cd-109</b>	1.00	1.03	1.04	1.11	1.42	3.05	7.61	22.1	63.0
<b>Ce-144</b>	1.00	1.03	1.04	1.11	1.21	1.49	2.05	4.24	9.30
<b>Co-57</b>	1.00	1.03	1.05	1.11	1.19	1.46	1.99	4.06	8.69
<b>Co-60</b>	1.00	1.04	1.06	1.13	1.23	1.52	2.12	4.39	9.81
<b>Cs-134</b>	1.00	1.07	1.10	1.19	1.30	1.61	2.22	4.57	10.1
<b>Cs-137</b>	1.00	1.10	1.14	1.28	1.41	1.75	2.41	4.98	11.0
<b>Eu-152</b>	1.00	1.03	1.05	1.10	1.19	1.47	2.03	4.20	9.28
<b>Fe-55</b>	1.00	2.12	3.12	9.97	27.1	71.6	149	284	484
<b>H-3</b>	1.00	1.06	1.08	1.38	2.18	5.97	16.4	51.3	150
<b>I-129</b>	1.00	1.19	1.34	1.90	3.14	8.92	25.0	79.1	233
<b>Mn-54</b>	1.00	1.03	1.05	1.12	1.22	1.50	2.08	4.30	9.52
<b>Na-22</b>	1.00	1.05	1.08	1.13	1.22	1.51	2.07	4.28	9.44
<b>Nb-94</b>	1.00	1.01	1.05	1.18	1.27	1.56	2.15	4.42	9.77
<b>Ni-63</b>	1.00	1.46	1.68	5.59	16.6	54.2	155	464	1180
<b>Pu-238</b>	1.00	1.02	1.04	1.82	2.50	3.26	4.24	6.01	8.88
<b>Pu-239</b>	1.00	1.02	1.03	1.83	2.51	3.28	4.26	6.07	8.94
<b>Ru-106</b>	1.00	1.01	1.02	1.07	1.36	2.65	7.23	14.9	32.7
<b>Sb-125</b>	1.00	1.03	1.05	1.10	1.18	1.45	1.99	4.10	8.94
<b>Sr-90</b>	1.00	1.17	1.23	4.04	11.9	37.1	98.7	285	729
<b>Tc-99</b>	1.00	1.02	1.07	1.54	2.55	7.16	20.0	62.8	185
<b>Th-232</b>	1.00	1.03	1.05	1.47	1.75	2.24	3.12	6.08	12.3
<b>U-235</b>	1.00	1.01	1.19	2.18	3.84	10.3	15.9	30.2	58.8
<b>U-238</b>	1.00	1.01	1.04	1.43	2.27	5.73	11.1	18.3	30.5
<b>Zn-65</b>	1.00	1.31	1.45	1.81	2.07	2.62	3.64	7.62	17.0



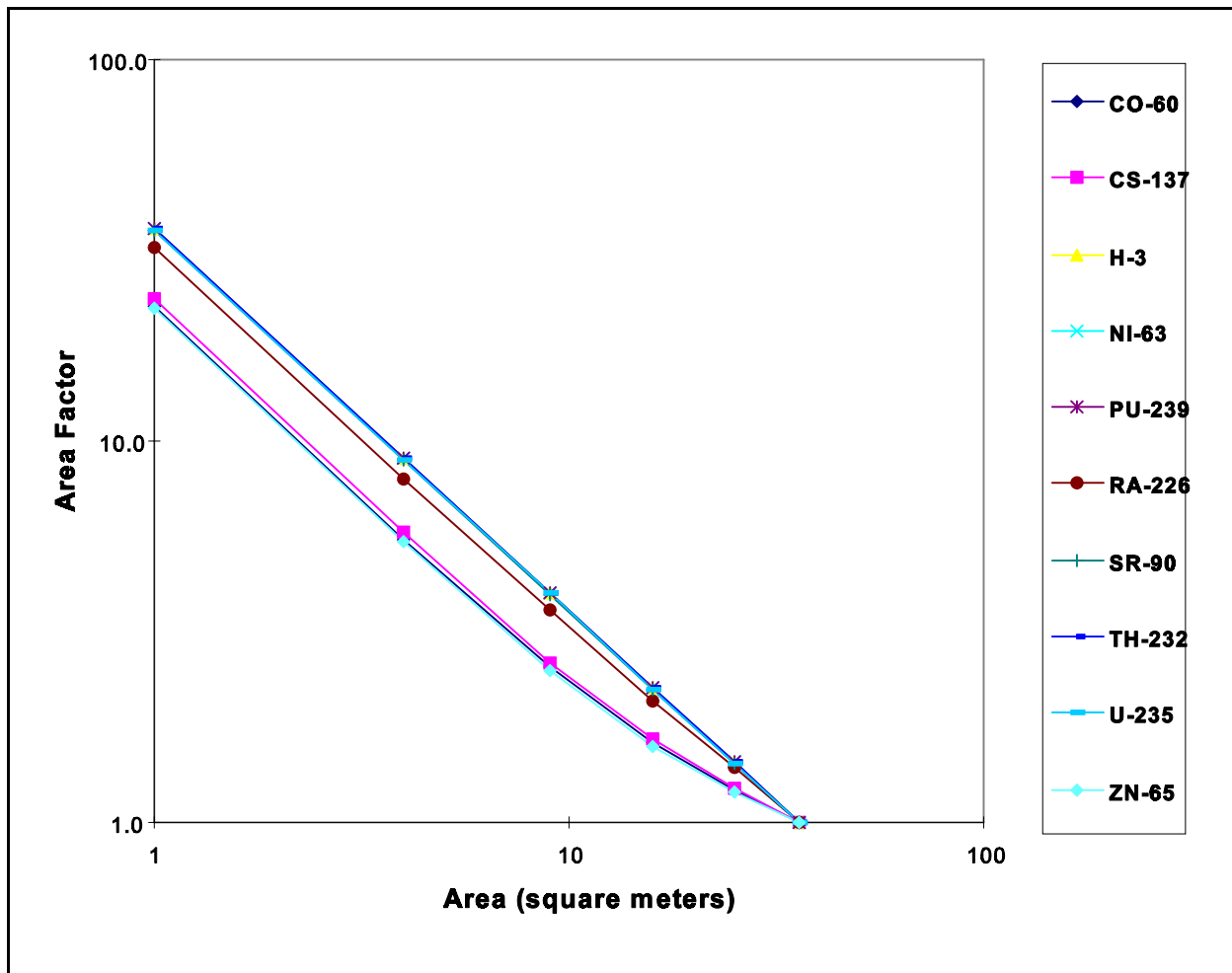
**Figure 8.2 Example Outdoor Area Factors**

The indoor area factors for selected radionuclides are plotted in Figure 8.3. There is not as much variation between radionuclides as there is with the outdoor area factors. All of the area factors scale nearly with the size of the contaminated area. As with the outdoor area factors, the radionuclides that deliver dose primarily through internal pathways have higher area factors than those that deliver dose primarily through the external pathway. The area factors for radionuclides that deliver dose primarily through internal pathways scale with the area in a manner suggesting

that it is the total inventory of the removable fraction of these radionuclides that is most important.

**Table 8.2 Example Indoor Area Factors**

Nuclide	36 m <sup>2</sup>	25 m <sup>2</sup>	16 m <sup>2</sup>	9 m <sup>2</sup>	4 m <sup>2</sup>	1 m <sup>2</sup>
Co-60	1.0	1.2	1.6	2.5	5.5	22.7
Cs-137	1.0	1.2	1.7	2.6	5.7	23.5
H-3	1.0	1.4	2.3	4.0	9.0	36.0
Ni-63	1.0	1.4	2.3	4.0	9.0	36.0
Pu-239	1.0	1.4	2.3	4.0	9.0	36.0
Ra-226	1.0	1.4	2.1	3.6	8.0	32.2
Sr-90	1.0	1.4	2.2	4.0	8.9	35.7
Th-232	1.0	1.4	2.3	4.0	9.0	36.0
U-235	1.0	1.4	2.2	4.0	9.0	35.8
Zn-65	1.0	1.2	1.6	2.5	5.4	22.3



**Figure 8.3 Example Indoor Area Factors**



The area factors for radionuclides that deliver dose primarily through external gamma have lower area factors, reflecting the fact that this dose can be delivered at a distance. Thus, in a mixture, it will generally be these radionuclides that will usually have the limiting area factors. However, the effect is not as large indoors as outdoors.

## 8.5 Example

A concrete room, 5 meters by 6 meters, had been contaminated with  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ , and subsequently remediated. The floor and the bottom 2 meters of the walls were to be surveyed as a Class 1 survey unit. Measurements were to be made for 100s at each grid point with a  $16\text{ cm}^2$  GM counter with a 10.1% efficiency. The  $\text{DCGL}_w$  for both nuclides were within about 10%, so the lower was taken to conservatively apply to both. This  $\text{DCGL}_w$ , about 1100 dpm per  $100\text{ cm}^2$ , translated into 30 counts per 100s with this detector. During the DQO process it was determined that Scenario A would be used with  $\alpha = 0.05$ ,  $\beta = 0.025$ , and  $\Delta = 10$  counts. The average background readings for this type of building on site had been about  $60 \pm 10$  counts, so the estimated  $\sigma = 10$ . From Table 3.3, it was found that 39 measurements each were required in the reference area and the survey unit. This was rounded up to 40. The survey unit area is  $61\text{ m}^2$ , so the spacing,  $L$ , on a triangular grid is  $L = [61 / (0.866N)]^{1/2} = [61 / (34.6)]^{1/2} = 1.3\text{ m}$ , using  $N = 40$ . The grid area is  $0.866 L^2 = 0.866 (1.3)^2 = 1.5\text{ m}^2$ . Interpolating into Table 8.2 gives an area factor for  $1.5\text{ m}^2$  of 15. This results in a  $\text{DCGL}_{\text{EMC}} = 15 (\text{DCGL}_w) = 16500\text{ dpm per } 100\text{ cm}^2$ , or 450 GM counts per 100s. This level is easily seen while scanning, so no additional grid measurements will be needed in order to find elevated areas.

When the random start triangular grid was laid out in the survey unit, 50 measurement locations were identified. When there are more locations identified than are required, they are all sampled and reported. In the reference area, the grid lay out was terminated when 40 locations were found. The data are shown in Table 8.3.

The mean and standard deviation of the reference area measurements was  $58 \pm 10$ . For the survey unit, these were  $88 \pm 92$ . The difference of the means,  $88 - 58$ , is just at the  $\text{DCGL}_w$  of 30. However the median in the reference area is 59 while that in the survey unit is only 58. This is an indication that the survey unit data is fairly symmetric, but that the survey unit mean is being driven up by a few very high measurements. This can be seen even more clearly in the combined ranked data plot of Figure 8.4. For this plot the reference area measurements, adjusted by adding the  $\text{DCGL}_w$  to each, are combined with the survey unit measurements. The measurements are then plotted against their rank in the combined data set, using different symbols for the reference area points and the survey unit points. This is an easier diagnostic plot to use than the Quantile-Quantile plot when the reference area and survey unit have different numbers of data points. From this plot it can be seen that the majority of the survey unit measurements fall below the adjusted reference area measurements, but that there are eight survey unit measurements that are much higher. One of those measurements exceeds the  $\text{DCGL}_{\text{EMC}}$ , which is equivalent to 450 GM counts per 100s. Thus, further investigation of this survey unit will be required before it could be released, regardless of the outcome of the WRS test.

The sum of the adjusted reference area ranks, shown in Table 8.3, is 2432. This is greater than the critical value of 2023 given by the equation following Table A.3 for  $n = 50$ ,  $m = 40$ , and  $\alpha = 0.05$ . Thus, the hypothesis that the survey unit as a whole *uniformly* exceeds the  $\text{DCGL}_w$  is

rejected. Whether or not the survey unit may be released is now dependent on the results of the investigation of the elevated measurements that were found.

A posting plot of the survey unit data is shown in Figure 8.5. In terms of GM counts, the elevated area is defined by the average reference area measurement plus the  $DCGL_w$ , which is  $58 + 30 = 88$ . The shaded area in Figure 8.5 encloses the measurements exceeding 88 GM counts per 100s. This area, which also encloses all of the measurements exceeding the  $DCGL_{EMC}$ , covers almost  $16 \text{ m}^2$ . From Table 8.2, the area factor for  $^{137}\text{Cs}$  is 1.7 and that for  $^{60}\text{Co}$  is 1.6. For a mixture of the two radionuclides, the smaller value is used. Thus, in this case the  $DCGL_{EA} = 1.6$  ( $DCGL_w$ ) = 1760 dpm per  $100 \text{ cm}^2$ , or 48 GM counts per 100s. The average of the ten measurements in the shaded area is 216.8 GM counts per 100s, which is  $216.8 - 58 = 158.8$  GM counts per 100s above the reference area average. Thus, the survey unit does not meet the release criterion, and may not be released without further remediation.

This example illustrates how the nonparametric statistical tests used in combination with the elevated measurement comparison work to assure that the release criterion is met.

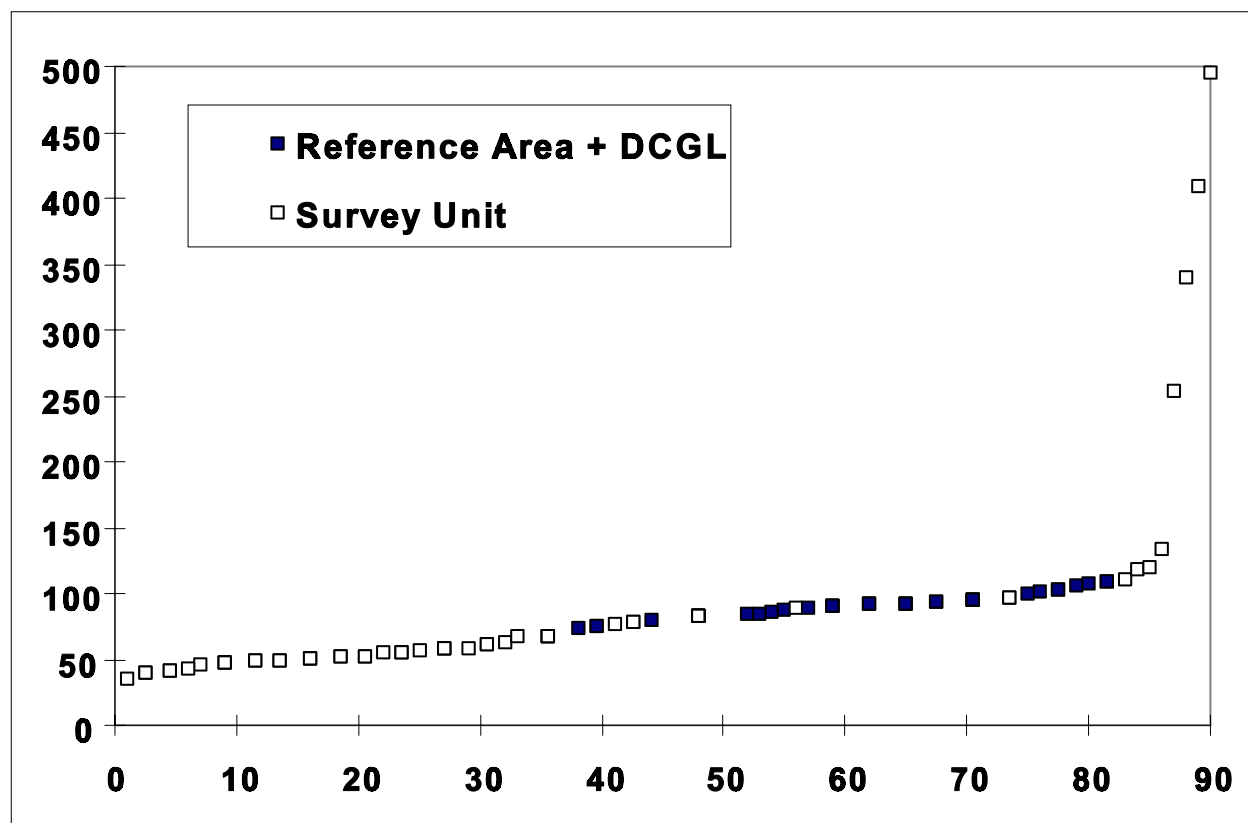


Figure 8.4 Combined Ranked Data Plot of Reference Area and Survey Unit Measurements

**Table 8.3 Data for Indoor Survey Unit and Reference Area**  
(GM counts per 100s)

Ref Data	Survey Data	Adjusted Ref Data	Ref Ranks	Survey Ranks
55	56	88	55	23.5
50	46	83	48	7
63	55	96	70.5	22
51	58	84	52	27
43	68	76	39.5	35.5
50	51	83	48	16
50	83	83	48	48
50	89	83	48	56
50	47	83	48	9
53	134	86	54	86
35	410	68	35.5	89
50	78	83	48	42.5
43	52	76	39.5	18.5
73	40	106	79	2.5
63	111	96	70.5	83
75	340	108	80	88
60	50	93	65	13.5
58	43	91	59	6
70	62	103	77.5	30.5
61	495	94	67.5	90
68	63	101	76	32
57	47	90	57	9
63	52	96	70.5	18.5
60	254	93	65	87
58	78	91	59	42.5
59	67	92	62	33
47	97	80	44	73.5
58	59	91	59	29
76	49	109	81.5	11.5
61	118	94	67.5	84
70	120	103	77.5	85
67	77	100	75	41
60	42	93	65	4.5
76	53	109	81.5	20.5
52	68	85	53	35.5
59	68	92	62	35.5
41	36	74	38	1
63	62	96	70.5	30.5
64	56	97	73.5	23.5
59	58	92	62	27
	47			9
	40			2.5
	50			13.5
	57			25
	58			27
	49			11.5
	53			20.5
	51			16
	42			4.5
	51			16
		Sum =	2432	1663

